Theseus in the M7 context

D. Götz on behalf of THESEUS France

The ESA M7 (and F) call

- https://www.cosmos.esa.int/web/call-for-missions-2021
- Global framework: Voyage 2050 (https://www.cosmos.esa.int/web/voyage-2050)
- Two phases process
  - Phase 1 proposal (10 pages) due by February 14th 2022: first evaluation of technical feasibility and scientific compelling (expected for mid-April)
  - Phase 2 proposal (50 pages) due by July 15th 2022: detailed technical and programmatic screening by ESA for assessing their feasibility and consulting the potential partners to the mission during the evaluation phase.
- Following this technical and programmatic screening, the selection process will be based on the scientific merit of the proposals, assessed through peer review under the responsibility of the ESA Science Advisory
  Structure

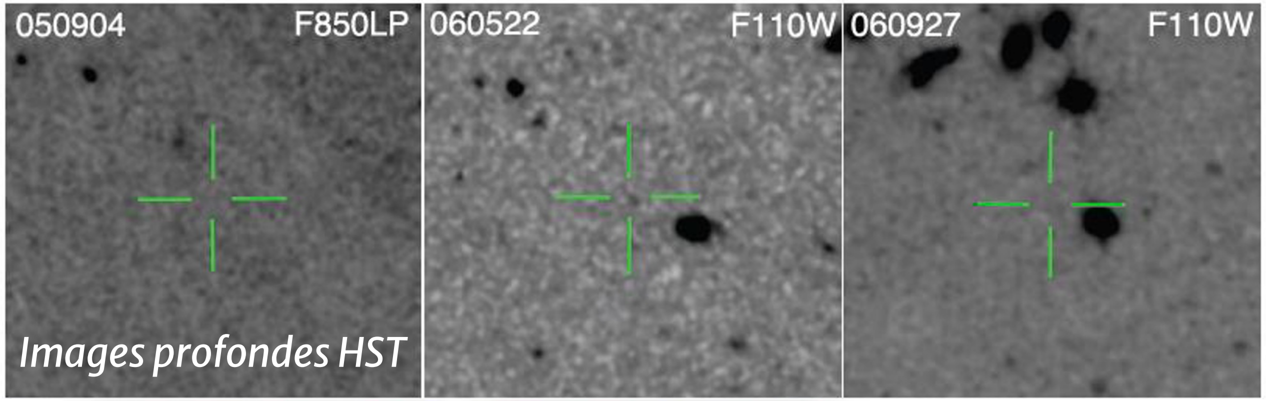
Planning & Boundary conditions

- Letters of endorsement deadline: 15 September 2022
- Selection of missions (up to 3 M and 1 F) for study: November 2022
- Start of Phase 0: Q1 2023
- Mission selection: 2026 (end of phase A)
- Mission adoption: 2029 (end of phase B1)
- Launch by 2037 (3 years on nominal mission lifetime)
- Boundary conditions are for M7 pretty identical to M5 (including 550 M€ cost cap!)

TheseUS?

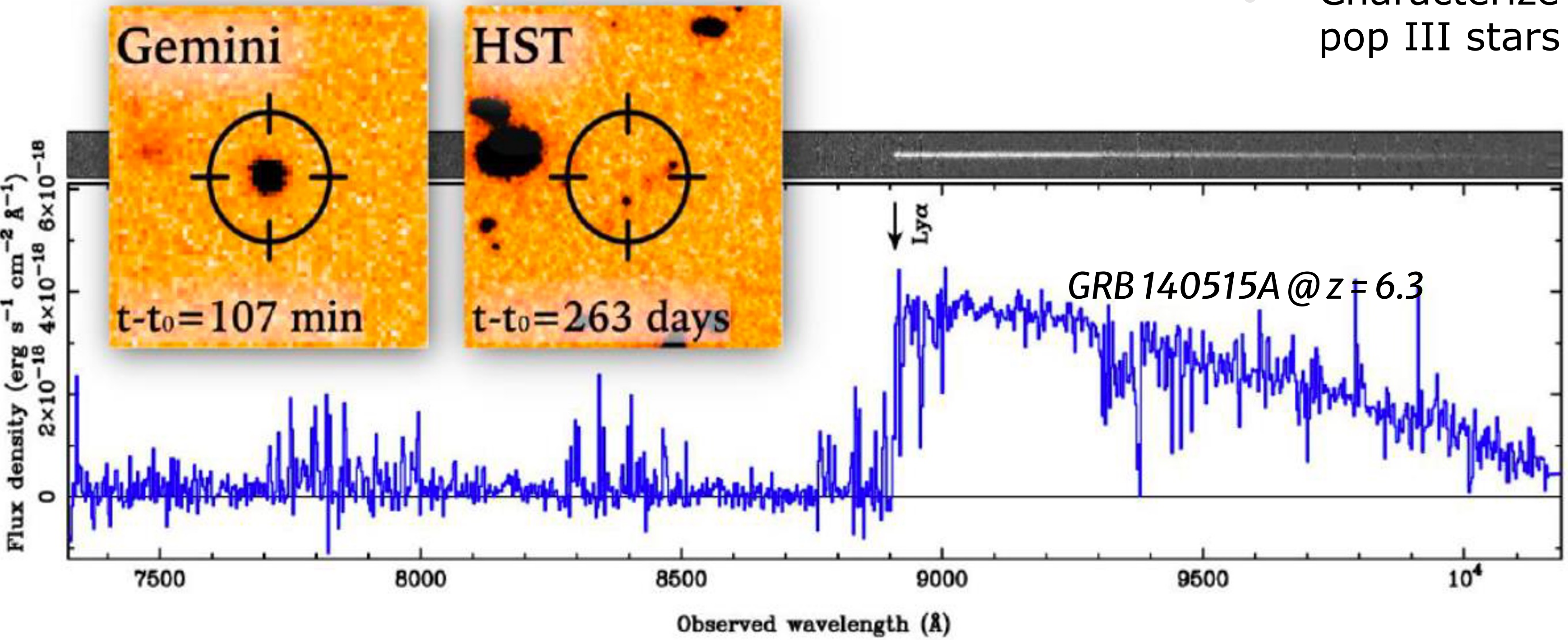
- Theseus has been selected for a competitive phase A for the M5 slot (launch ~2032)
- At the end of a successful phase A study (mission declared feasible and scientifically compelling) it has not been selected for launch in favour to EnVision
- The detailed technical studies produces for M5 can be reused for M7, and no doubt on the feasibility is expected
- The costs have been evaluated in detail and exceed the original cost cap by 65 M€ -> NASA has been contacted in order to cover some M5 ESA costs (NIR detectors, X-ray detectors, NIR OTA, near-real time alert system,…). If NASA agrees (fits with decadal survey), no need for descoping for Theseus M7 vs M5 -> Under study at JPL!
- A trade-off can be addressed in phase A: LEO vs. L2 orbit (lesson learnt from M5)

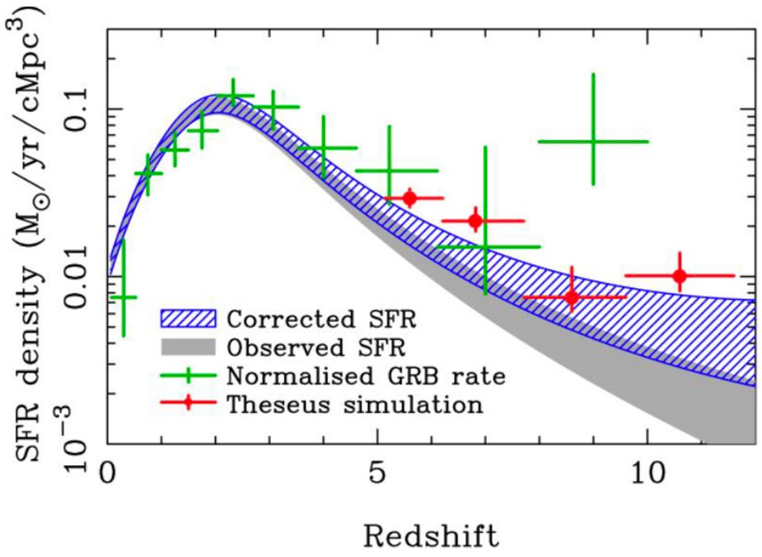
Gamma-Ray Bursts as Cosmological Tools



Gamma-Ray Bursts allow to investigate the first billion years of the Universe and in particular to

- Investigate the nature of the first galaxies and stars
- Identify the sources which contributed to the reionization of the Universe
- Characterize the star formation history up to pop III stars



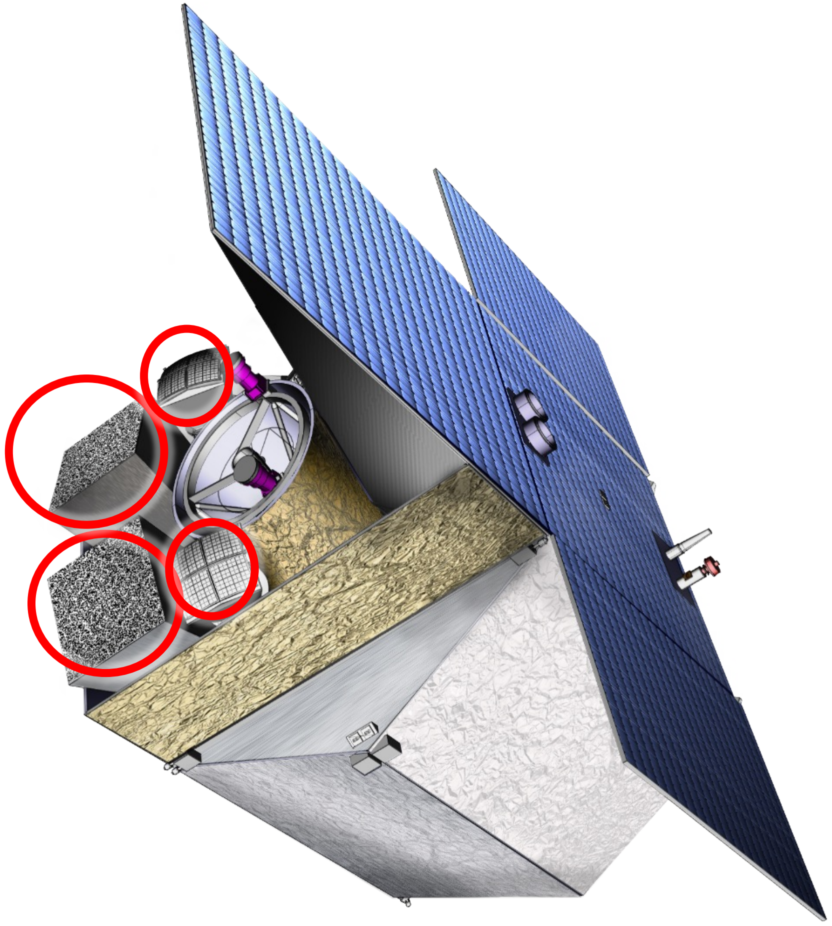


THESEUS

(ESA/M5 Phase A study in 2018-2021)

THIS BREAKTHROUGH WILL BE ACHIEVED BY A MISSION CONCEPT OVERCOMING MAIN LIMITATIONS OF CURRENT FACILITIES

Set of innovative wide-field monitors with **unprecedented combination of broad energy range, sensitivity, FOV and localization accuracy**



THESEUS

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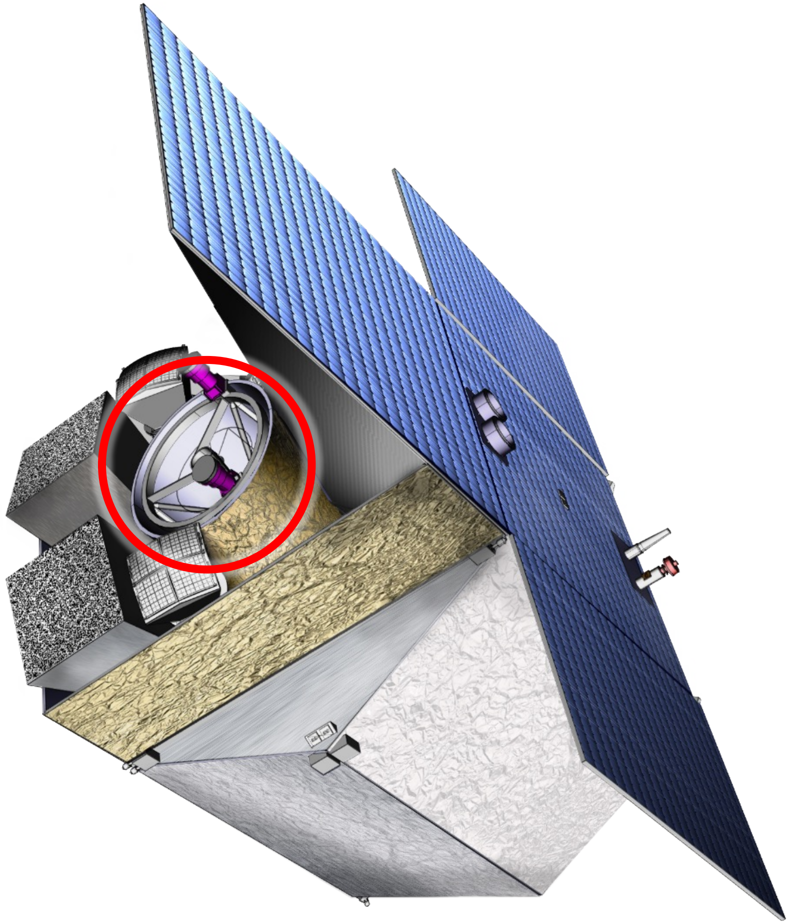
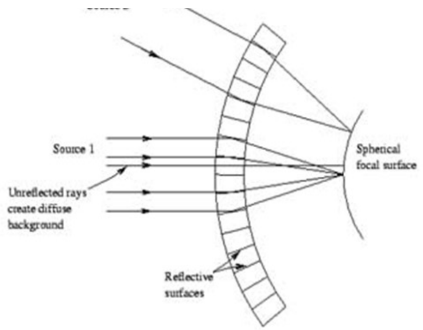
Set of innovative wide-field monitors with **unprecedented combination of broad energy range, sensitivity, FOV and localization accuracy**

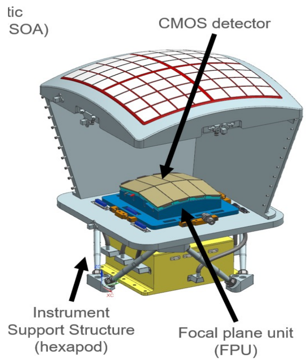
On-board **autonomous fast follow-up** in optical/NIR, arcsec location and **redshift measurement** of detected GRB/transients



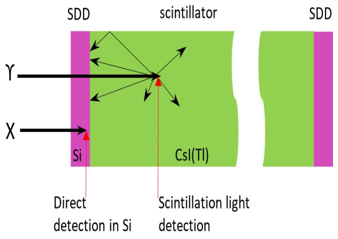
THESEUS

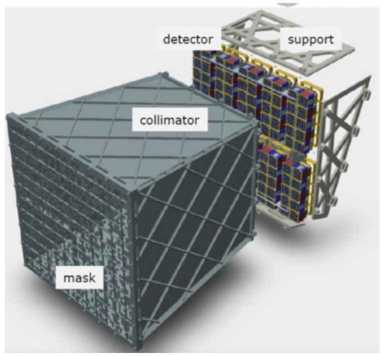
- **Soft X-ray Imager (SXI):** a set of two sensitive lobster-eye telescopes observing in 0.3 - 5 keV band, total FOV of ~0.5sr with source location accuracy <2′ 



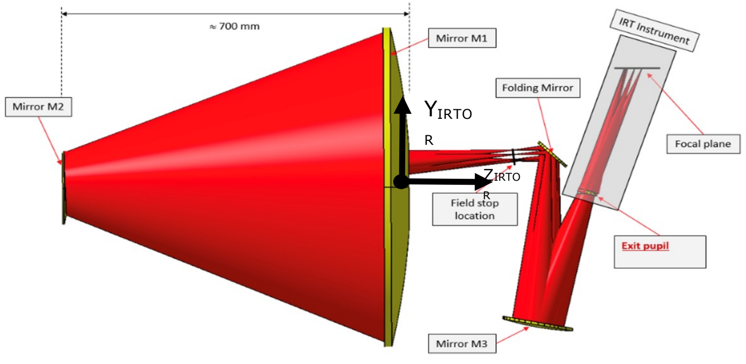


- **X-Gamma rays Imaging Spectrometer (XGIS):** 2 coded-mask X-gamma ray cameras using Silicon drift detectors coupled with CsI crystal scintillator bars observing in 2 keV – 10 MeV band, a FOV of >2 sr, overlapping the SXI, with <15′ GRB location accuracy 





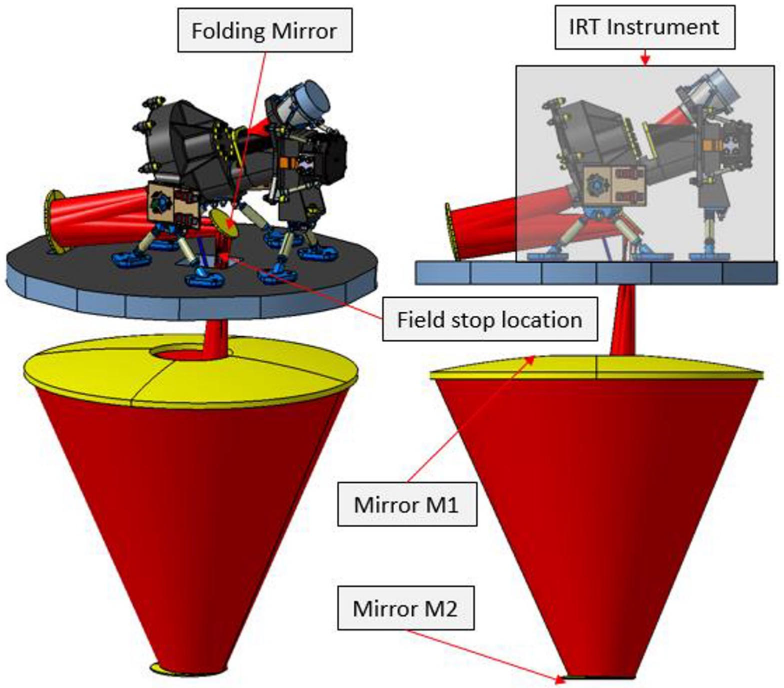
- **InfraRed Telescope (IRT):** a 0.7m class IR telescope observing in the 0.7 – 1.8 μm band, providing a 15′x15′ FOV, with both imaging and moderate resolution spectroscopy capabilities 

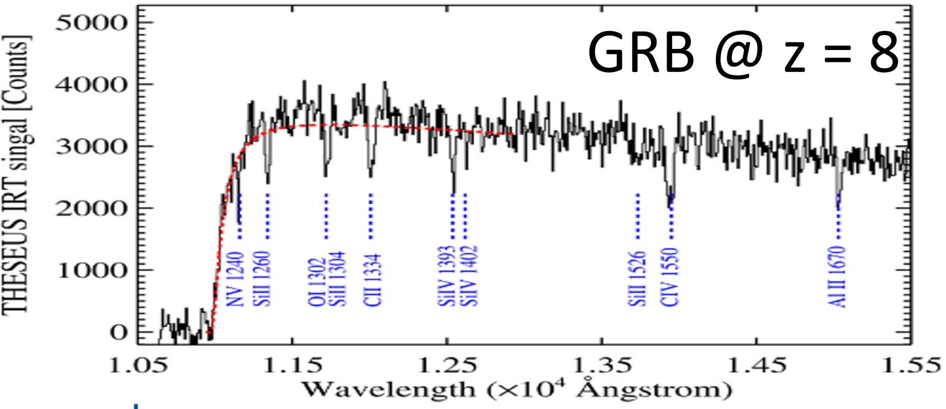


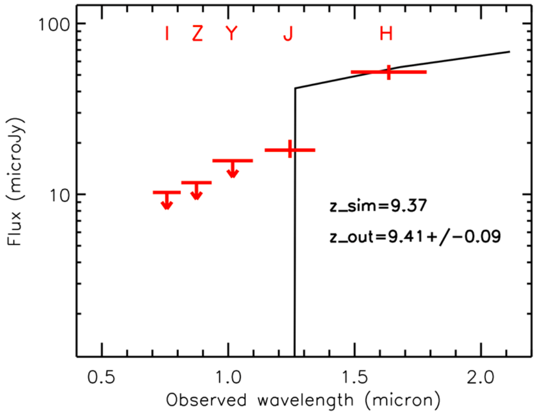
The IRT Telescope

The main goal of the IRT telescope is to identify and measure the distance of the counterparts of the Theseus GRBs in real time on board, with specific focus on high z (>6; photometric redshift).

In addition IRT will spectrally characterize the sources (spectroscopic redshift, neutral hydrogen, presence of metals, …) and will be used as an agile observatory in space for multi-messengers astronomy.

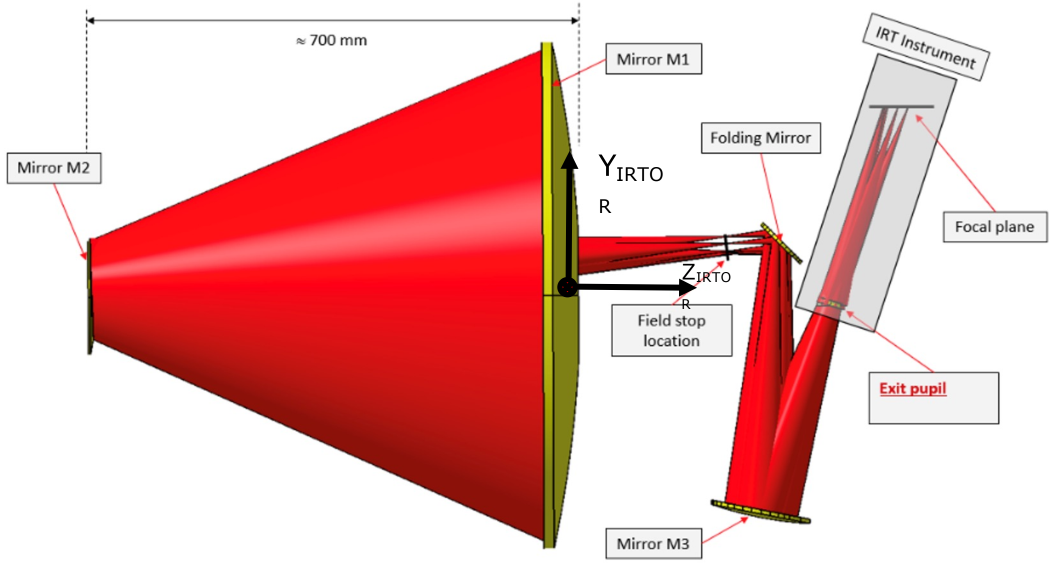


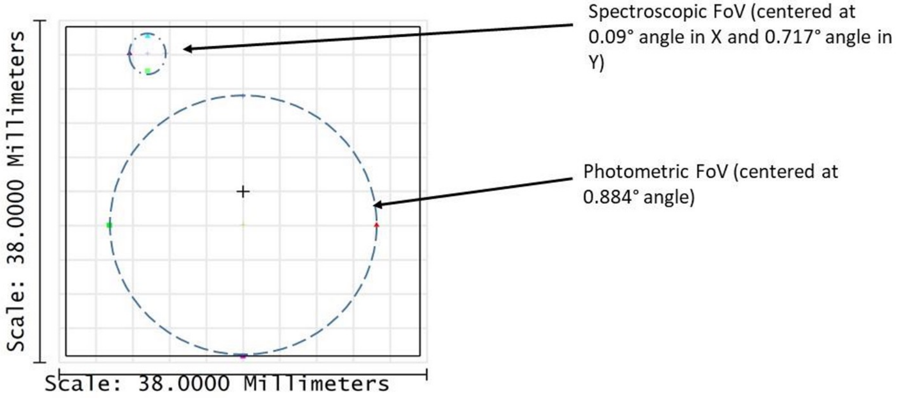




cnes · Irfu Institut de recherche sur les lois fondamentales de l'Univers · LAM Laboratoire d'Astrophysique de Marseille · Eberhard Karls Universität Tübingen · CBK PAN · l'Observatoire de Paris GEPI · APC · Université de Genève

IRT Optical design



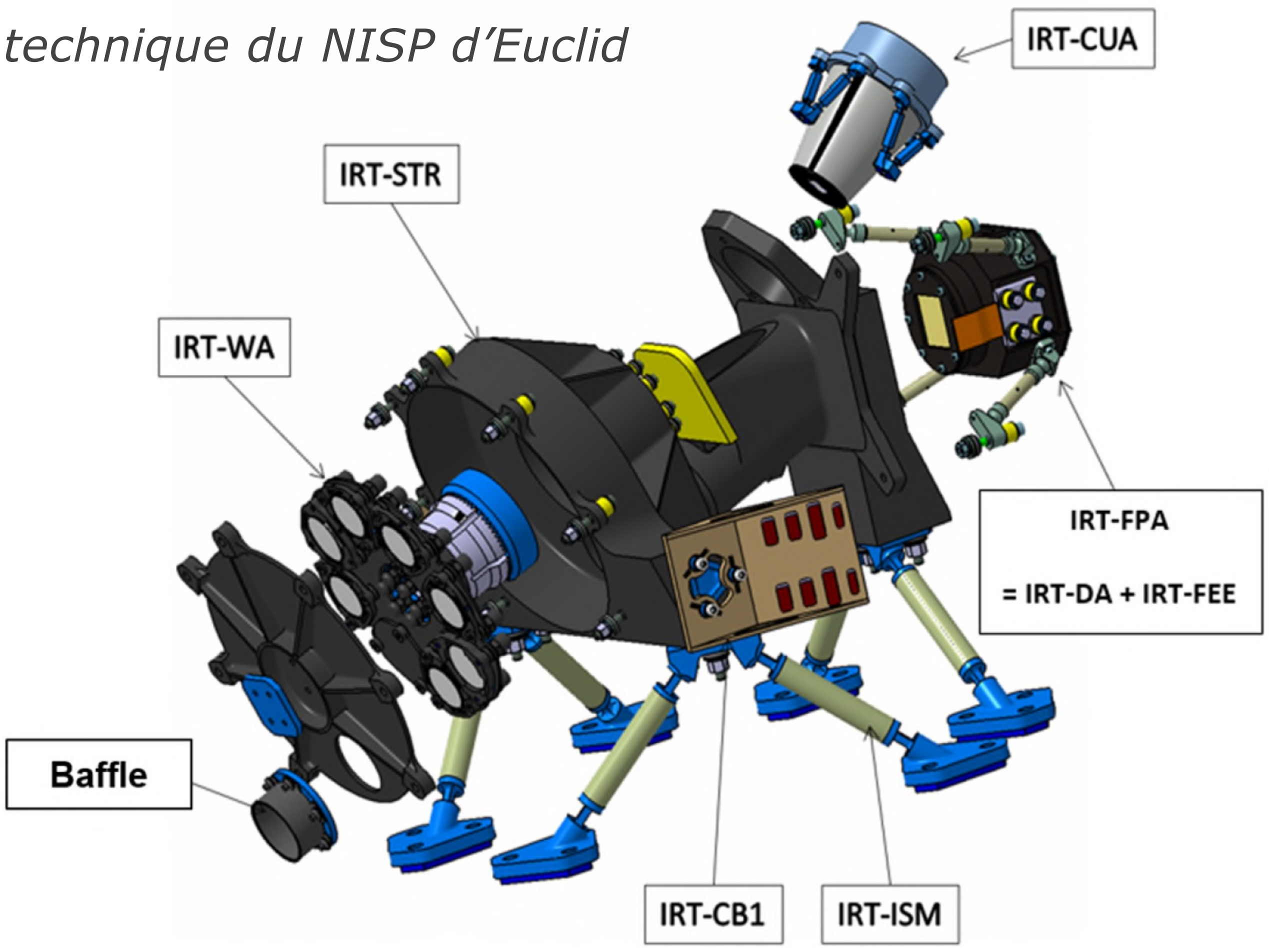


The IRT Telescope is under ESA responsibility
Optical interface at telescope exit pupil where the filter wheel (with filters and grism) is located.

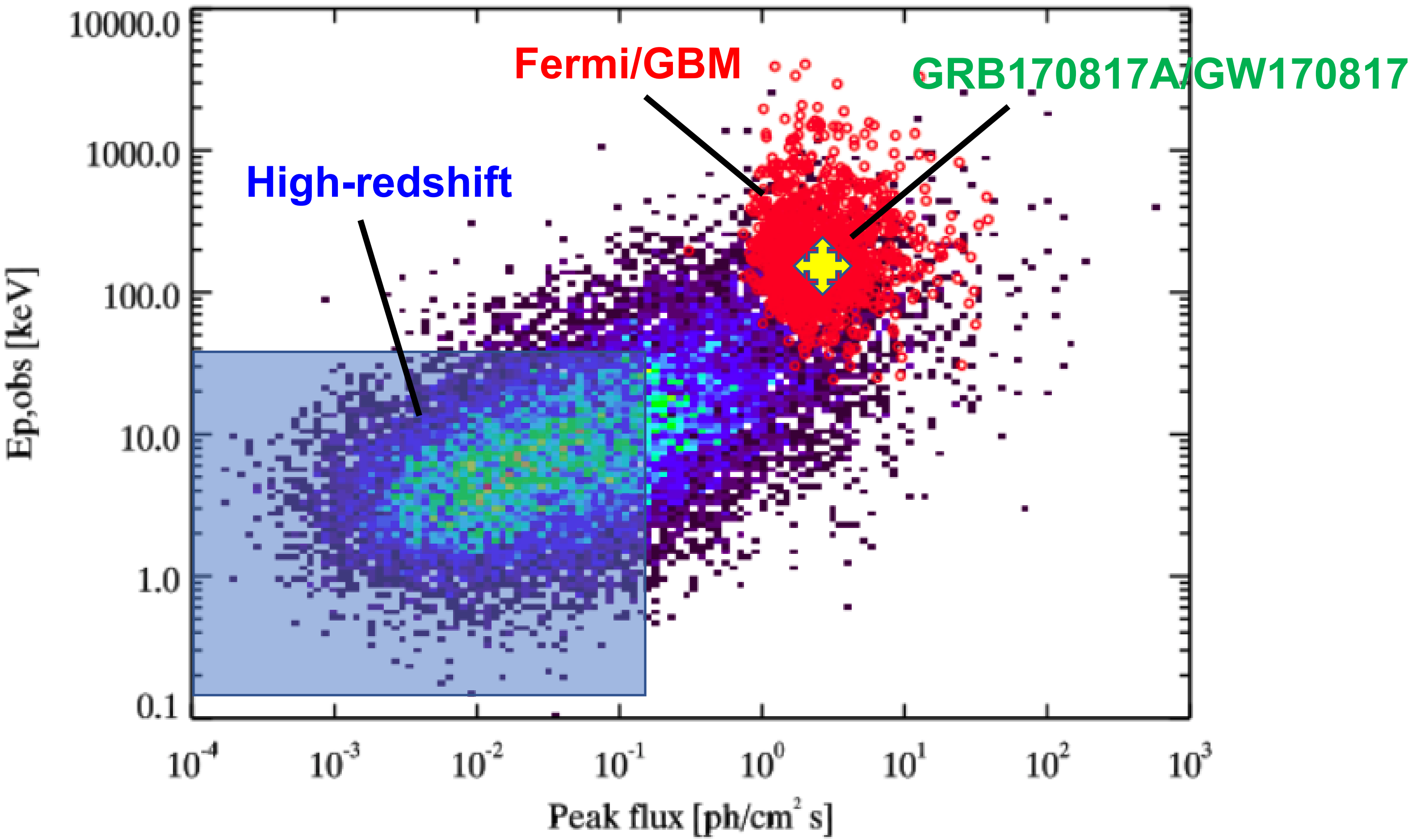
IRT design characteristics	
Type	Focusing on-axis Korsch observing off-axis FoVs
Entrance pupil	700 mm (M1 rim)
Collecting area	> 0.34 m^2
M1-M2 distance	675 mm
Focal length	6188 mm
Exit pupil	35 mm
Pixel scale	0.6 arcsec/pixel for an IRT detector pixel pitch of 18 µm
Field of view	Photometry: 15′ x 15′ (goal: 19.8′ x 15.3′) Spectroscopy: 2′ x 2′ Separation: 1′
LoS (photometric)	Photometry: 0.884° from M1-M2 axis of symmetry
Wavelength range	700-1800 nm fot photometry (filters IZYJH) 800-1600 nm for spectroscopy
Spectroscopic resolving power	400
Image quality requirement (at 1800 nm wavelength)	50% of the encircled energy diameter < 1.28 arcsec 80% of the encircled energy diameter < 2.29 arcsec
Temperature	240 K for telescope – 140 K for instrument

IRT instrument

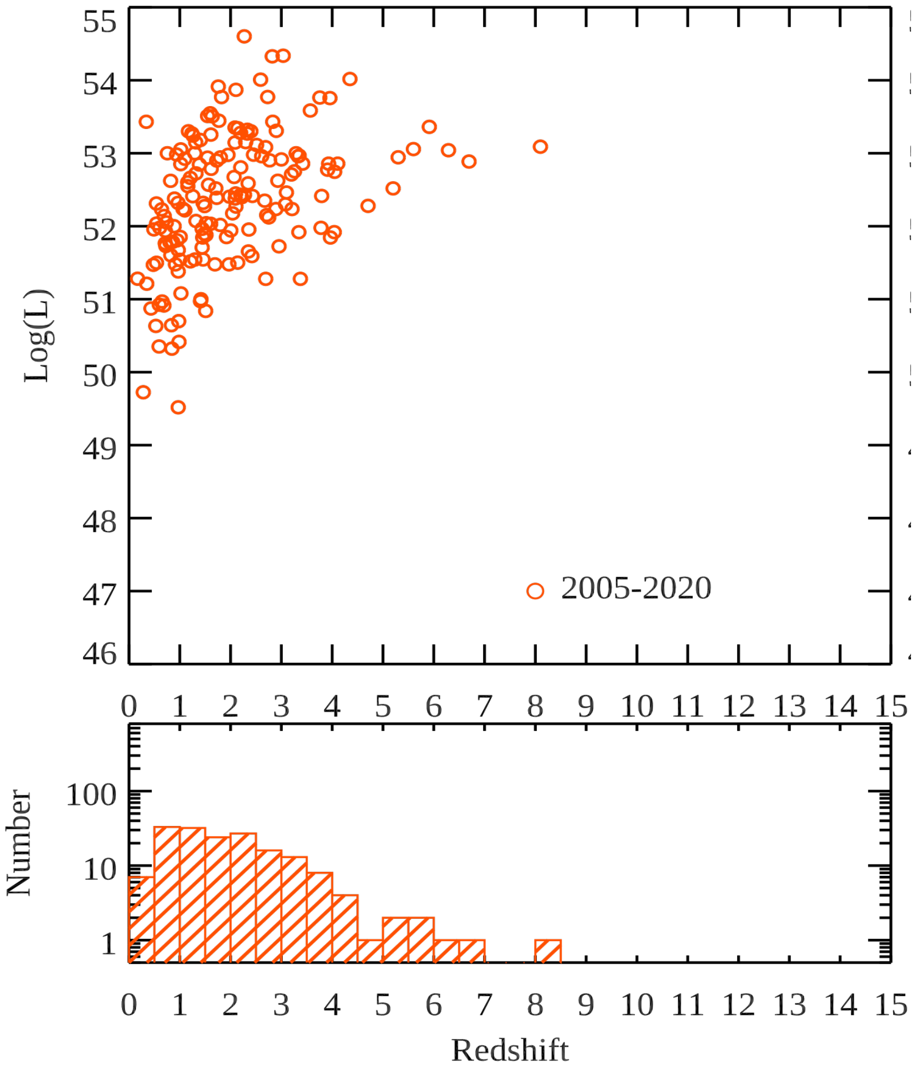
Heritage technique du NISP d'Euclid

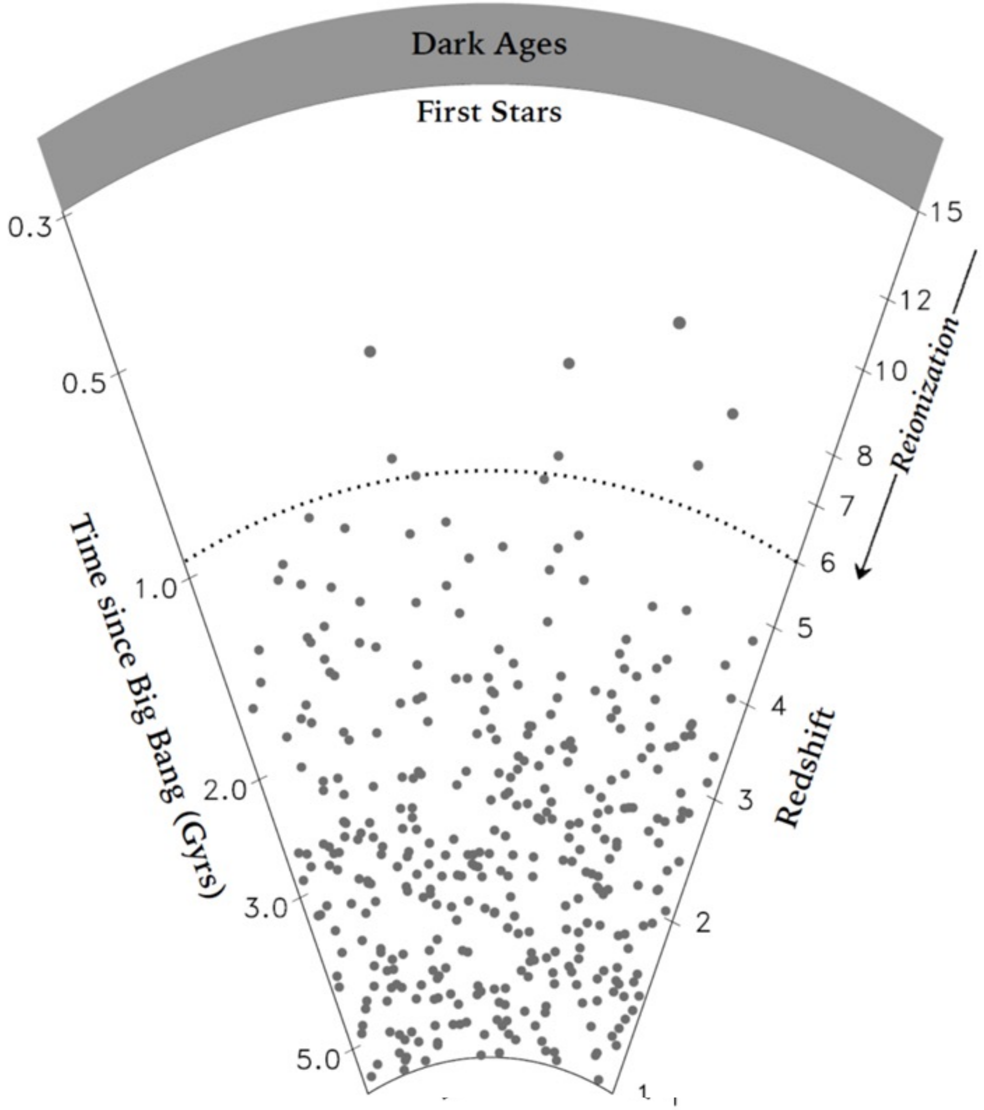


THESEUS will have the ideal combination of instrumentation and mission profile for detecting all types of GRBs (long, short/hard, weak/soft, high-redshift), providing accurate location and redshift for a large fraction of them

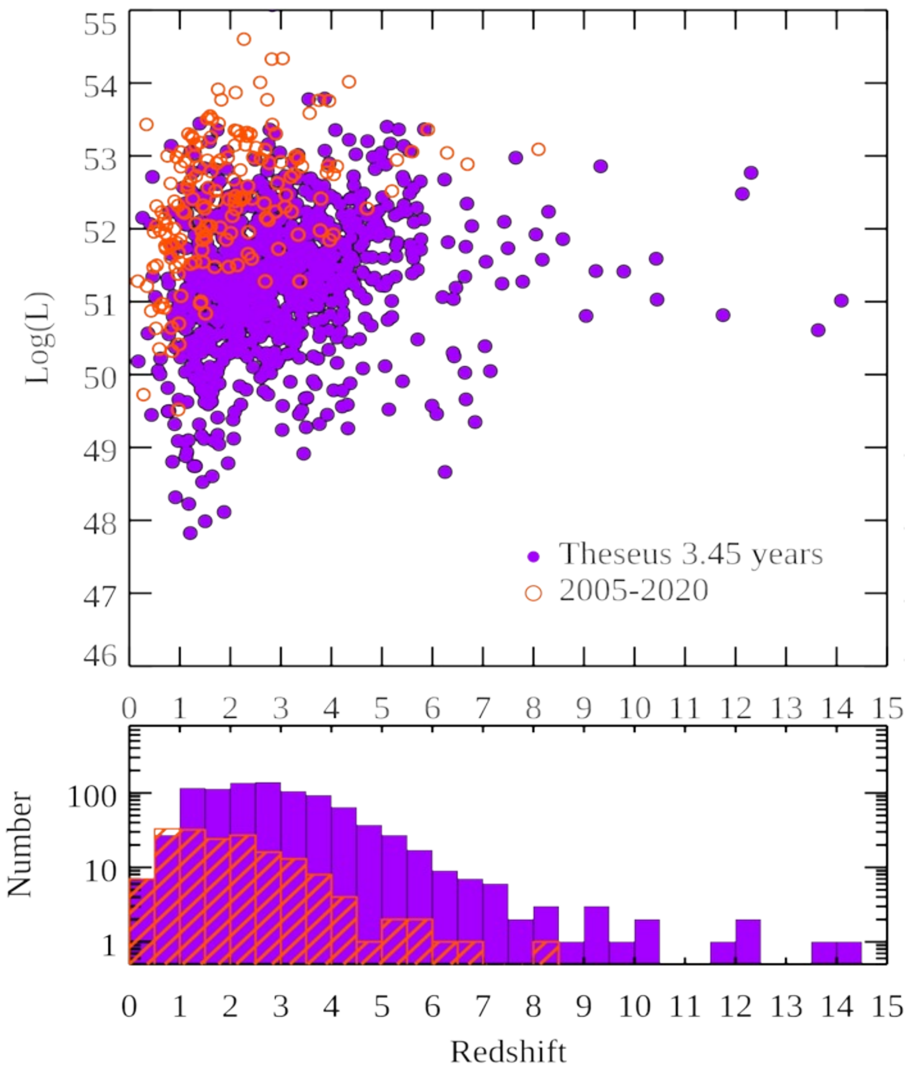


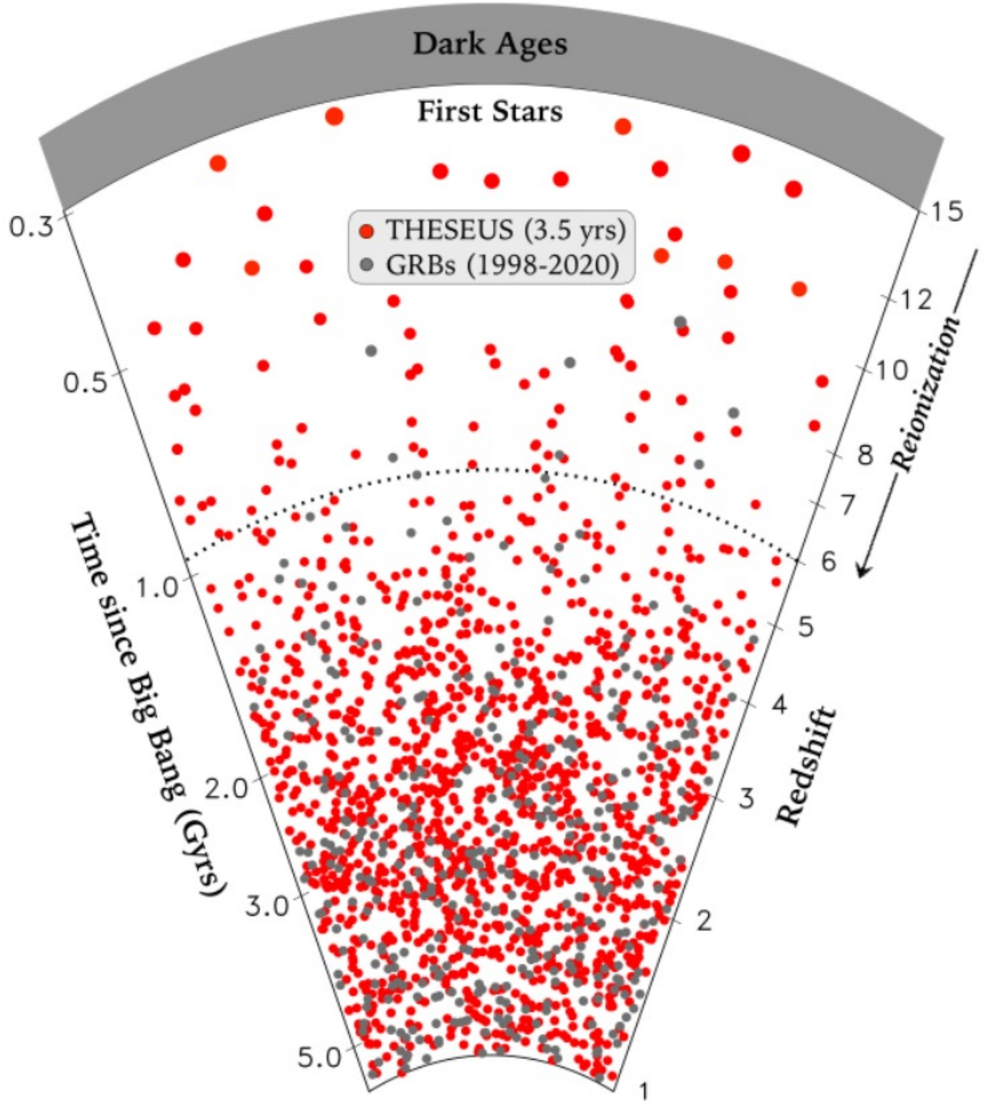
Shedding light on the early Universe with GRBs





Shedding light on the early Universe with GRBs





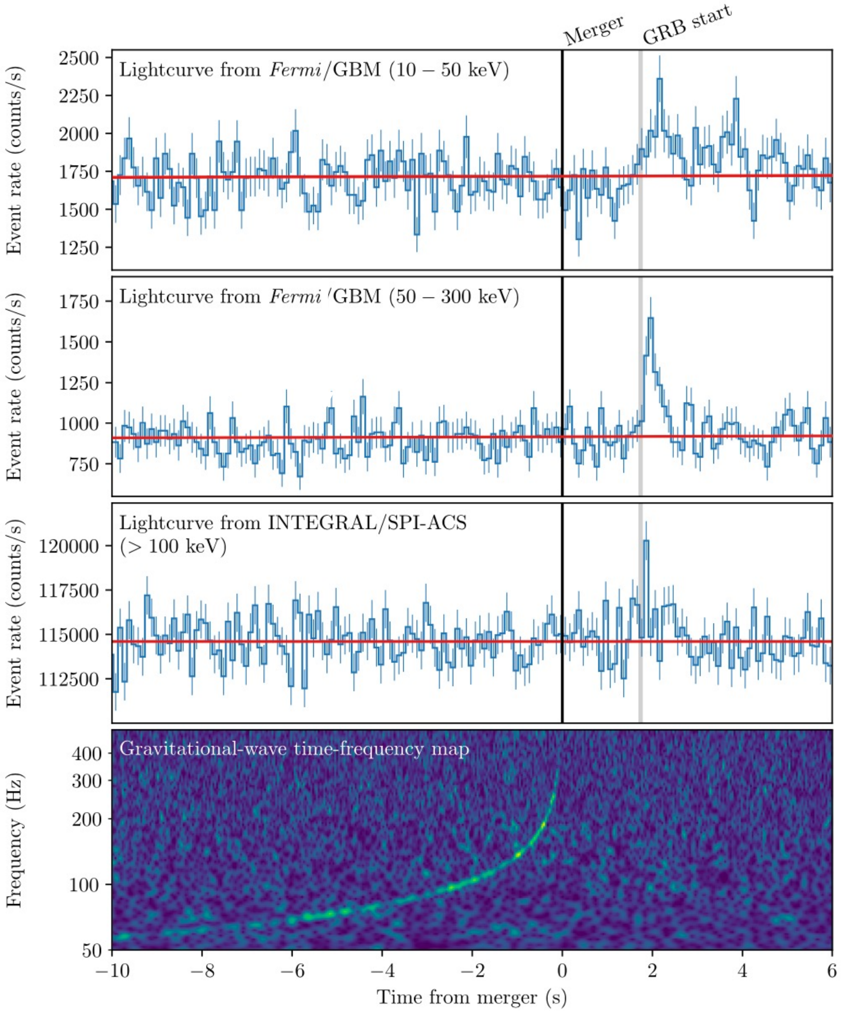
Still scientifically compelling in 2037?

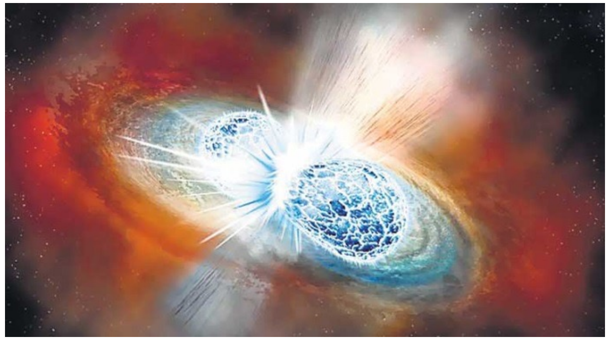
- Theseus science is based on two pillars
- Cosmology with GRBs -> study SFR, metallicity, physics of re-ionization and first stars/galaxies in general.
  - No major mission is planned on that area before, unless NASA selects a probe type mission to be flown before 2037.
    - THESEUS (studied for ESA Cosmic Vision / M5), HiZ-GUNDAM (JAXA, under study), TAP (idea for NASA probe-class mission, not mentioned in the decadal survey), Gamow Explorer (proposal for NASA MIDEX, ~Theseus pathfinder)
    - JWST is expected to detected massive galaxies at z 10-12, but smaller ones can only be pinpointed by GRBs.

- To be discussed at the Theseus Workshop on May 11th-12th

Short GRBs: a key phenomenon for multi-messenger astrophysics

GW170817 + SHORT GRB 170817A + KN AT2017GFO (~40 Mpc):
the birth of multi-.messenger astrophysics



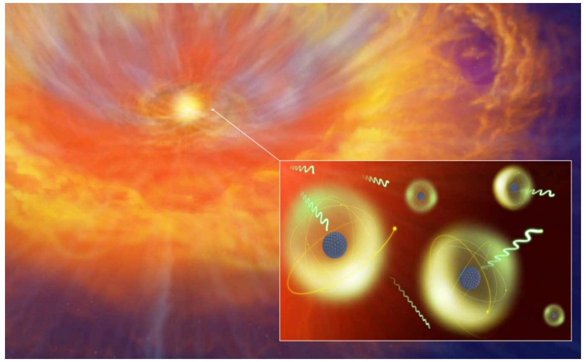


GRB: a key phenomenon for multi-messenger astrophysics (and cosmology)

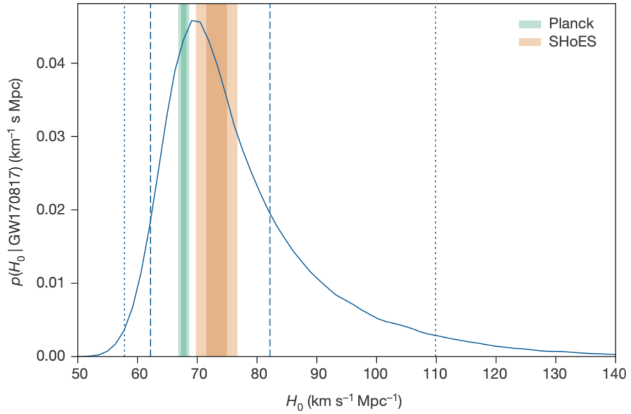
GW170817 + SHORT GRB 170817A + KN AT2017GFO
THE BIRTH OF MULTI-MESSENGER ASTROPHYSICS

Relativistic jet formation, equation of state, fundamental physics

Cosmic sites of r-process nucleosynthesis

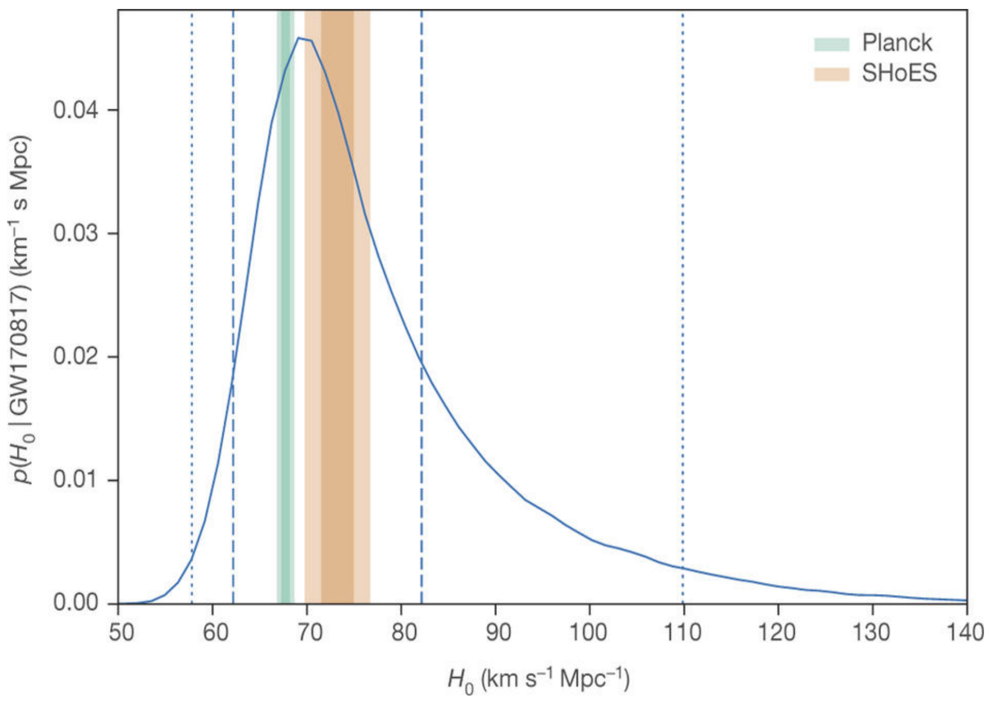


New independent route to measure cosmological parameters

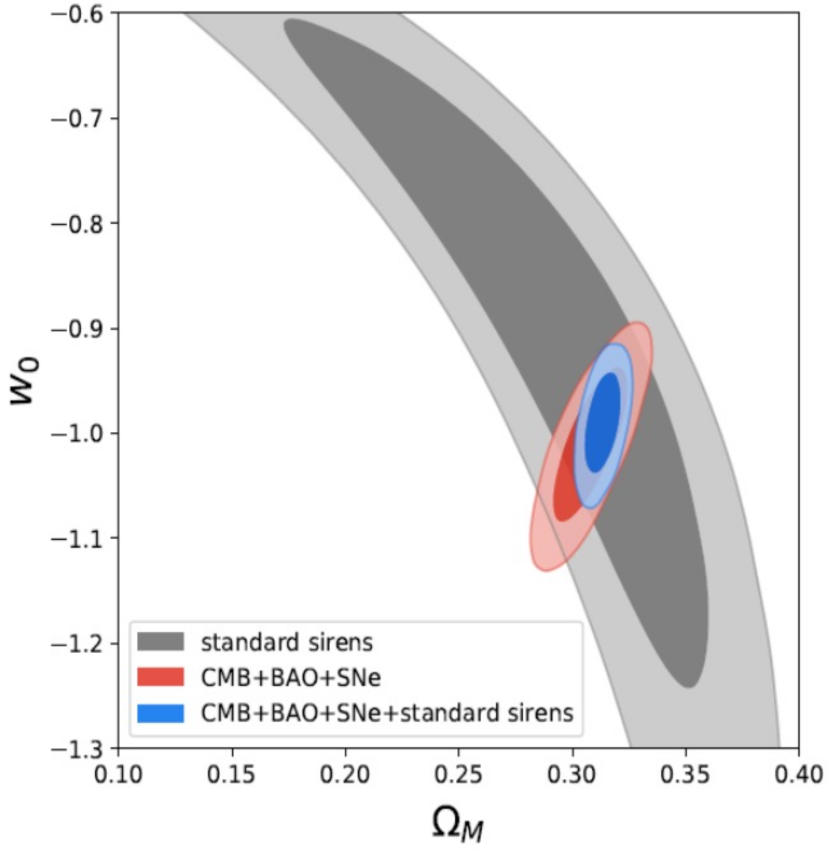


GRB: a key phenomenon for multi-messenger astrophysics (and cosmology)

MEASURING THE EXPANSION RATE AND GEOMETRY OF SPACE-TIME

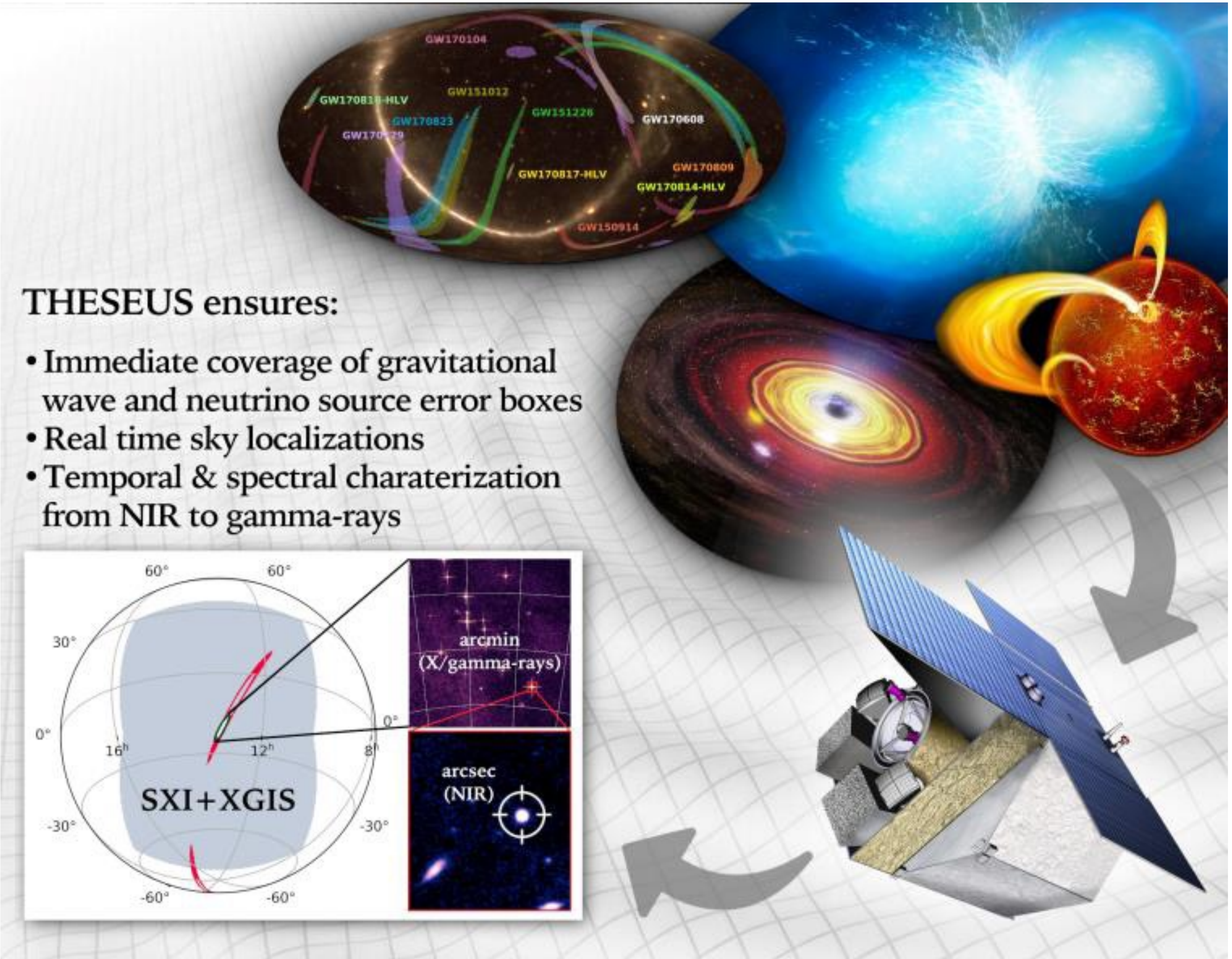


Estimating H0 with GW170817A (LVC 2017)



Investigating dark energy with a statistical sample of GW + e.m. (Sathyaprakash et al. 2019)

Exploring the multi-messenger transient sky

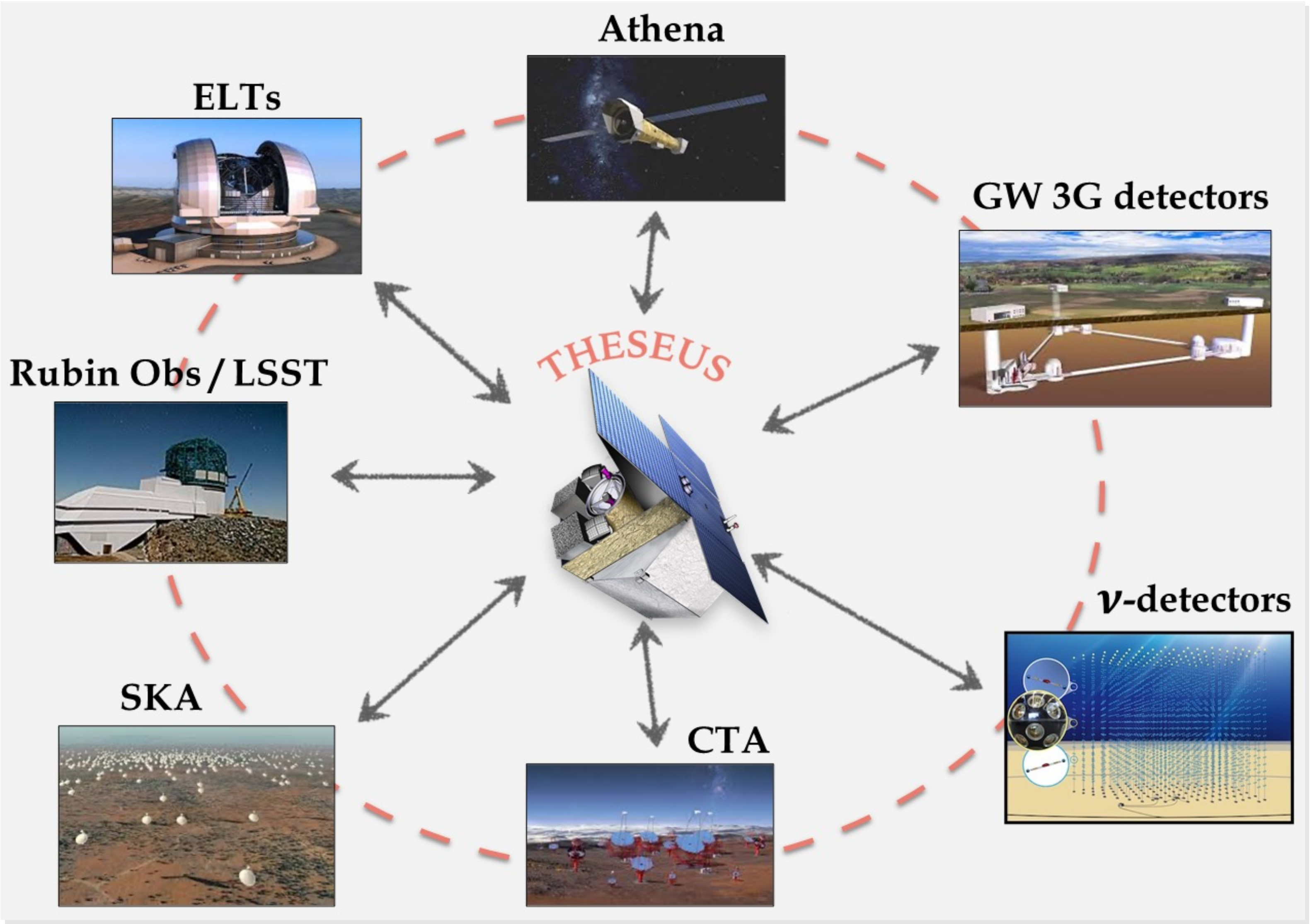


Future GRB missions: synergies

- **Many next generation large observatories of the near** future (e.g., SKA, CTA, ATHENA, LSST, ELT, TMT, JWST) have GRB-related science in their core-science programmes

- **GRBs as key phenomenon for multi-messenger astrophysics** (GW, neutrinos): synergy with, e.g., advanced LIGO/VIRGO KAGRA, I-LIGO and, in perspective, 3G detectors (ET, CE) and possibly LISA.

Multi-wavelength/messenger synergies

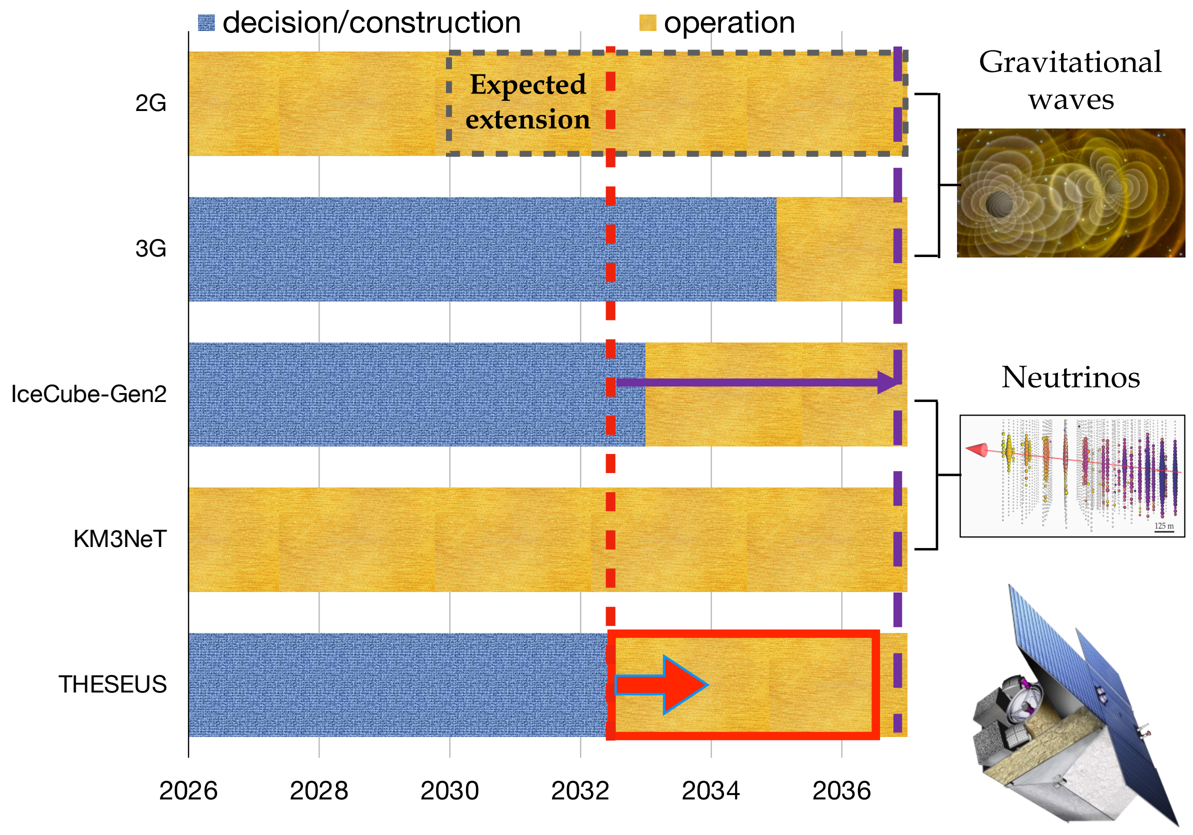


Amati+ 2021

Synergy with future MM detectors

ENTERING THE GOLDEN ERA OF MULTI-MESSENGER ASTROPHYSICS

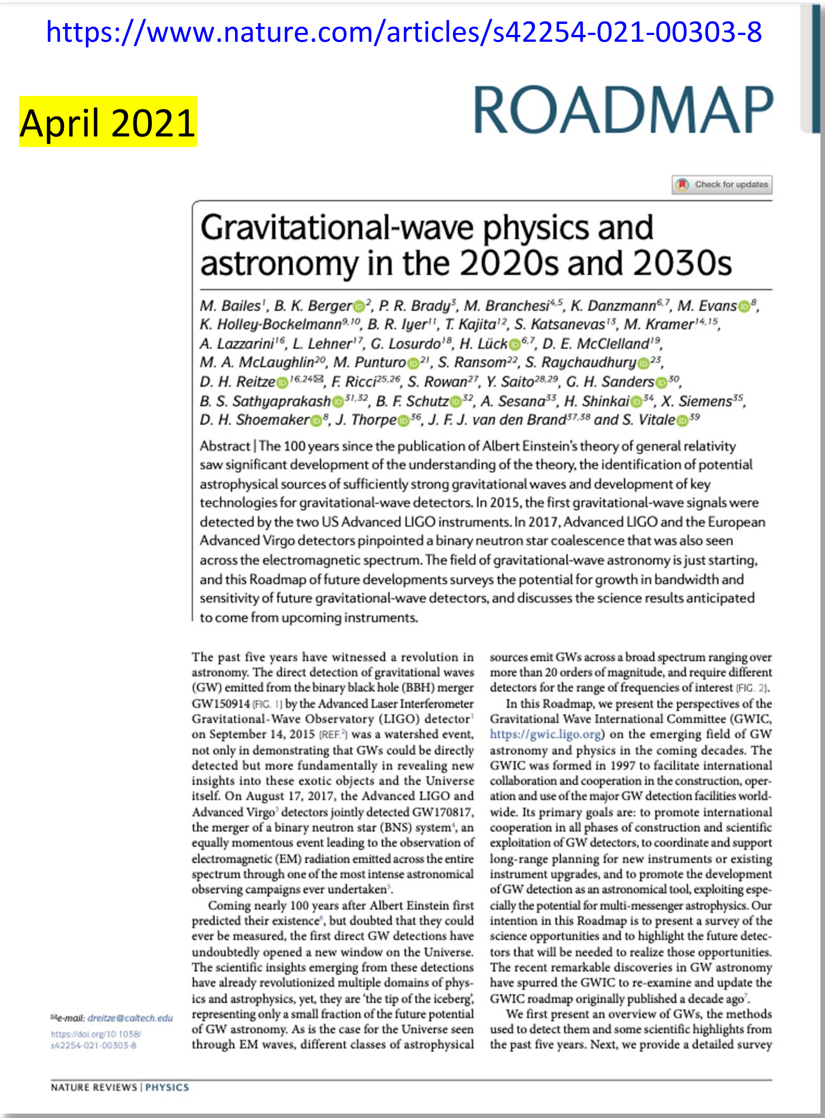
Synergy with future GW and neutrino facilities will enable transformational investigations of multi-messenger sources



+ LISA > 2037

https://www.nature.com/articles/s42254-021-00303-8

April 2021


ROADMAP

Check for updates

Gravitational-wave physics and astronomy in the 2020s and 2030s

M. Bailes[1], B. K. Berger[2], P. R. Brady[3], M. Branchesi[4,5], K. Danzmann[6,7], M. Evans[8], K. Holley-Bockelmann[9,10], B. R. Iyer[11], T. Kajita[12], S. Katsanevas[13], M. Kramer[14,15], A. Lazzarini[16], L. Lehner[17], G. Losurdo[18], H. Lück[6,7], D. E. McClelland[19], M. A. McLaughlin[20], M. Punturo[21], S. Ransom[22], S. Raychaudhury[23], D. H. Reitze[16,24]✉, F. Ricci[25,26], S. Rowan[27], Y. Saito[28,29], G. H. Sanders[30], B. S. Sathyaprakash[31,32], B. F. Schutz[32], A. Sesana[33], H. Shinkai[34], X. Siemens[35], D. H. Shoemaker[8], J. Thorpe[36], J. F. J. van den Brand[37,38] and S. Vitale[39]

Abstract | The 100 years since the publication of Albert Einstein's theory of general relativity saw significant development of the understanding of the theory, the identification of potential astrophysical sources of sufficiently strong gravitational waves and development of key technologies for gravitational-wave detectors. In 2015, the first gravitational-wave signals were detected by the two US Advanced LIGO instruments. In 2017, Advanced LIGO and the European Advanced Virgo detectors pinpointed a binary neutron star coalescence that was also seen across the electromagnetic spectrum. The field of gravitational-wave astronomy is just starting, and this Roadmap of future developments surveys the potential for growth in bandwidth and sensitivity of future gravitational-wave detectors, and discusses the science results anticipated to come from upcoming instruments.

The past five years have witnessed a revolution in astronomy. The direct detection of gravitational waves (GW) emitted from the binary black hole (BBH) merger GW150914 (FIG. 1) by the Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO) detector[1] on September 14, 2015 (REF.[2]) was a watershed event, not only in demonstrating that GWs could be directly detected but more fundamentally in revealing new insights into these exotic objects and the Universe itself. On August 17, 2017, the Advanced LIGO and Advanced Virgo[3] detectors jointly detected GW170817, the merger of a binary neutron star (BNS) system[4], an equally momentous event leading to the observation of electromagnetic (EM) radiation emitted across the entire spectrum through one of the most intense astronomical observing campaigns ever undertaken[5].

Coming nearly 100 years after Albert Einstein first predicted their existence[6], but doubted that they could ever be measured, the first direct GW detections have undoubtedly opened a new window on the Universe. The scientific insights emerging from these detections have already revolutionized multiple domains of physics and astrophysics, yet, they are 'the tip of the iceberg', representing only a small fraction of the future potential of GW astronomy. As is the case for the Universe seen through EM waves, different classes of astrophysical sources emit GWs across a broad spectrum ranging over more than 20 orders of magnitude, and require different detectors for the range of frequencies of interest (FIG. 2).

In this Roadmap, we present the perspectives of the Gravitational Wave International Committee (GWIC, https://gwic.ligo.org) on the emerging field of GW astronomy and physics in the coming decades. The GWIC was formed in 1997 to facilitate international collaboration and cooperation in the construction, operation and use of the major GW detection facilities worldwide. Its primary goals are: to promote international cooperation in all phases of construction and scientific exploitation of GW detectors, to coordinate and support long-range planning for new instruments or existing instrument upgrades, and to promote the development of GW detection as an astronomical tool, exploiting especially the potential for multi-messenger astrophysics. Our intention in this Roadmap is to present a survey of the science opportunities and to highlight the future detectors that will be needed to realize those opportunities. The recent remarkable discoveries in GW astronomy have spurred the GWIC to re-examine and update the GWIC roadmap originally published a decade ago[7].

We first present an overview of GWs, the methods used to detect them and some scientific highlights from the past five years. Next, we provide a detailed survey

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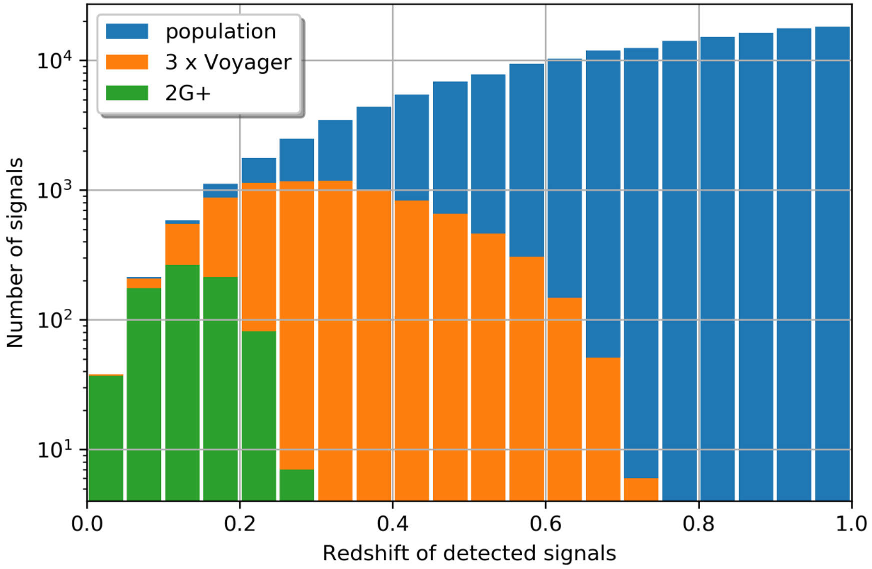
https://doi.org/10.1038/s42254-021-00303-8

GWIC Roadmap and Letter of Endorsement from EGO/virgo clearly mention further upgrades of 2G to bridge in the 3G era

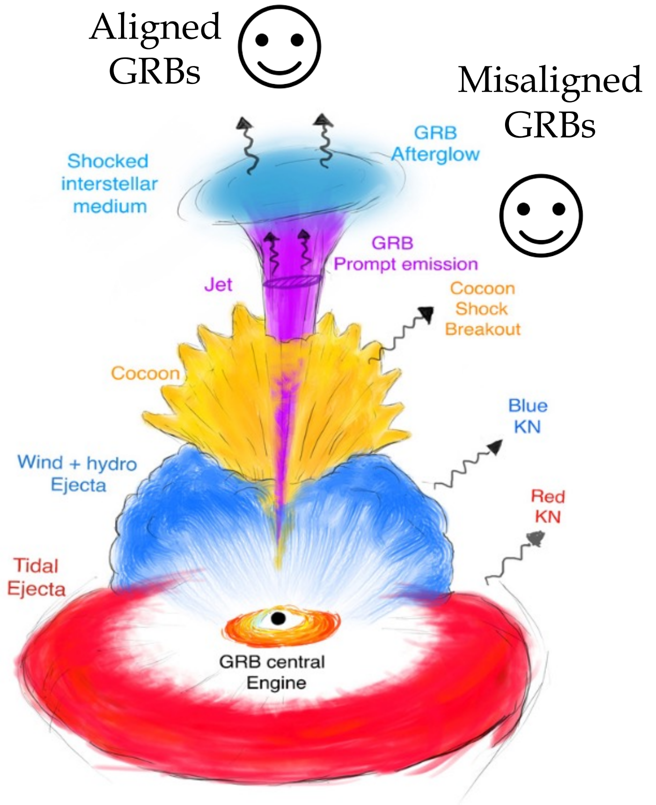


NS-NS merger detection efficiency with 2G and 2G++ will sensibly improve at z>0.1 with 2G++

Multi-messenger science with THESEUS

INDEPENDENT DETECTION & CHARACTERISATION OF THE MULTI-MESSENGER SOURCES

Lessons from GRB170817A



Expected rates:

THESEUS + 2G++:

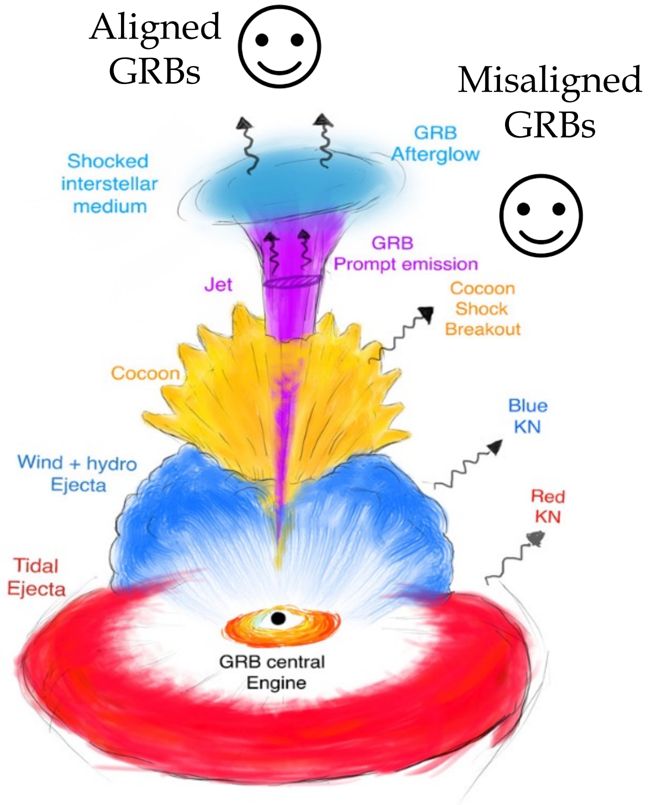
- ~10 yr aligned+misaligned collimated short GRBs
- ~50/yr isotropic X-ray transients from possible NS-NS merger remnant

Low redshifts events: detailed study of kilonovae, jet structure, remnant nature

Multi-messenger science with THESEUS

INDEPENDENT DETECTION & CHARACTERISATION OF THE MULTI-MESSENGER SOURCES

Lessons from GRB170817A



Expected rates:

THESEUS + 3G:

- ~50 aligned+misaligned short GRBs
- ~200 X-ray transients

Higher redshift events – X/γ is likely only route to EM detection: larger statistical studies including source evolution, probe of dark energy and test modified gravity on cosmological scales

Conclusions

- France has a leading scientific and technical in THESEUS (IRT, consortium coordination)

- Key contributions to the payload and ground segment (pipelines et Instrument Centre) will allow to the French community to fully exploit THESEUS scientific return

- THESEUS represents the scientific heritage of SVOM (and EP) allowing the French community to keep a leading role in Europe and worldwide on transient and multi-messenger Universe in the 2020s, 2030s and beyond.

- In view of the endorsement by CNES (September 2022) we need to verify/consolidate the French contribution. A dedicated workshop will be organized in June.